# INVESTIGATIONS OF NANOCOOLANT BASED $Al_2O_3$ FOR IMPROVING COOLING PERFORMANCE IN HOT PRESS FORMING

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UNIVERSITI MALAYSIA PAHANG

## SUPERVISOR’S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science in Manufacturing Engineering.

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**STUDENT’S DECLARATION**

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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# ABSTRAK

Pembentukan kepingan keluli panas (HPF) untuk membangunkan UHSS boron keluli untuk panel badan dalaman kenderaan menawarkan penggunaan bahan api yang efisien untuk mengurangkan pelepasan gas karbon dioksida oleh pengurangan berat badan dan meningkatkan keselamatan penumpang kerana sifat mekanikal yang tinggi. Boron keluli dipanaskan sehingga suhu austenitik dan kemudian disejutkan dengan cepat dalam sebuah acuan dalam masa pelindapkejutan tertentu untuk mempamerkan fasa transformasi martensit. Pada masa ini, air digunakan sebagai cecair penyejuk dalam proses HPF untuk menghilangkan keluli boron dalam sebuah acuan tertutup dengan saluran bendalir penyejukan. Walau bagaimanapun, untuk meningkatkan prestasi acuan HPF dan meningkatkan sifat mekanikal boron keluli ditekan panas, bendalir dengan sifat termal yang lebih baik akan digunakan dan bukannya air biasa. Semasa operasi pelindapkejutan, kadar cecair penyejukan optimum dan pengagihan suhu homogen pada kekosongan panas ke arah pencapaian transformasi mikrostruktur martensitic serta sifat mekanikal yang tinggi. Kajian ini menyebarkan nanopartikel $Al_2O_3$ dari kepekatan isipadu sebanyak 0.2 hingga 1.0% dengan purata diameter 13 nm ke dalam tiga peratusan air ke etilena glikol seperti 60%:40%, 50%:50%, dan 40%: 60% dengan menggunakan kaedah penyediaan dua langkah. Kedua-dua parameter utama dalam prestasi kadar cecair penyejukan adalah kekonduksian terma dan kelikatan dinamik. Pengedaran pemindahan haba pekali panas dengan nanocoolant dan air sejuk disimulasikan untuk analisis haba sementara dalam simulasi unsur terhingga melalui ANSYS untuk menilai peningkatan pekali pemindahan haba konveksi dan menentukan kadar cecair penyejukan optimum bendalir penyejukan sistem dalam acuan HPF. Data simulasi kemudian dibandingkan dengan penemuan eksperimen untuk tujuan pengesahan. Telah didapati bahawa peningkatan kekonduksian terma tertinggi adalah 10% lebih tinggi daripada bendalir asas untuk kepekatan volum 1,0% $Al_2O_3$ pada 55 °C dalam 60%:40% (W/EG). Walau bagaimanapun, peningkatan kelikatan dinamik yang paling tinggi diukur sebanyak 39% untuk kepekatan volum 1.0% $Al_2O_3$ dalam 40%:60% (W/EG) pada 25 °C. Koefisien pemindahan haba konveksi kepekatan 1.0% dalam 60%:40% (W/EG) pada 25 °C ditingkatkan dengan 25.4% lebih baik daripada 50%:50% dan 40%:60% (W/EG) cecair. Oleh itu, kajian ini memperakukan penggunaan $Al_2O_3$ dalam campuran 60%:40% (W/EG) dengan kepekatan volum $Al_2O_3$ kurang daripada 1.0% untuk aplikasi dalam saluran bendalir penyejukan acuan HPF. Itu juga terbukti bahawa corak pengedaran suhu model analisis unsur terhingga bersesuaian dengan hasil eksperimen. Kekuatan tegangan dan nilai kekerasan Vickers bahagian yang ditekan panas dinilai masing-masing kira-kira 1,550 MPa dan 588 HV. Sebagai kesimpulan, nanocoolant sebagai cecair penyejuk dengan pekali pemindahan haba konveksi yang lebih tinggi berbanding dengan air sejuk boleh mengurangkan masa pelindapkejutan dalam proses HPF.

**ABSTRACT**

Hot press forming (HPF) to develop UHSS of boron sheet metals for vehicle inner body panels offers efficient fuel consumption in order to reduce carbon dioxide gas emissions by weight reduction and improves passenger safety because of its high mechanical properties. The sheet metal is heated up to austenitic temperature and then rapidly quenched in an enclosure dies in a certain quenching time to exhibit martensitic transformation phase. Currently, water is used as coolant in the HPF process to quench boron steels in a closed die with a cooling channel. However, to enhance the performance of HPF dies and increase the mechanical properties of hot pressed boron steel, the fluid with better thermal properties will be used instead of normal water. During the quenching operation, an optimum cooling rate and homogeneous temperature distribution on hot blanks towards the achievement of the martensitic microstructure transformation as well as high mechanical properties. This study dispersed $Al_2O_3$ nanoparticles from the range of 0.2 to 1.0% volume concentration with an average diameter of 13 nm into three volume percentages of water to ethylene glycol such as 60%:40%, 50%:50%, and 40%:60% by using the two-step preparation method. The two main parameters in cooling rate performance are thermal conductivity and dynamic viscosity. The heat transfer distribution of the hot blanks with nanocoolant and chilled water are simulated for transient thermal analysis in finite element simulation via ANSYS to evaluate the enhancement of convection heat transfer coefficient and determine the optimum cooling rate of cooling system in HPF tool. The simulation data were then compared with experimental findings for validation purpose. It was found that the highest enhancement of thermal conductivity was observed to be 10% higher than base fluid for 1.0% volume concentration of $Al_2O_3$ at 55 °C in 60%:40% (W/EG). However, the highest enhancement of dynamic viscosity was measured to be 39% for 1.0% volume concentration of $Al_2O_3$ in 40%:60% (W/EG) at 25 °C. The convective heat transfer coefficient of 1.0% concentration in 60%:40% (W/EG) at 25 °C is enhanced by 25.4% better than that of 50%:50% and 40%:60% (W/EG) base fluid. Therefore, this study recommends the use of $Al_2O_3$ in 60%:40% (W/EG) mixture with volume concentration of $Al_2O_3$ less than 1.0% for application in cooling channel of HPF dies. It was also evident that the pattern of the temperature distribution of the finite element analysis model was in agreement with the experimental results. The tensile strength and Vickers hardness values of the hot pressed parts were evaluated to be approximately 1,550 MPa and 588 HV, respectively. In conclusion, nanocoolant as cooling fluid with higher convection heat transfer coefficient compared to the chilled water can reduce the quenching time of HPF process.

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| | |
|---|---|
| $A$ | Heat transfer area |
| $B$ | Bending length |
| $C_{bf}$ | Specific heat of base fluid |
| $C_{nf}$ | Specific heat of nanocoolant |
| $C_p$ | Specific heat of particle |
| $D$ | Pipe length |
| $dT$ | Temperature difference |
| $dX$ | Differential length |
| $E$ | Modulus elasticity |
| $h$ | Heat transfer coefficient |
| $k$ | Thermal conductivity |
| $k_{bf}$ | Thermal conductivity of base fluid |
| $k_{nf}$ | Thermal conductivity of nanocoolant |
| $L$ | Length |
| $Nu$ | Nusselt number |
| $P$ | Loading force |
| $Pr$ | Prandtl number |
| $Pr$ | Prandtl number of nanocoolant |
| $q$ | Heat transfer |
| $Re$ | Reynolds number |
| $s$ | Second |
| $t$ | Thickness |
| $T_1$ | Inlet temperature |
| $T_2$ | Outlet temperature |
| $T_b$ | Bulk temperature |
| $T_f$ | Surrounding fluid temperature |
| $T_s$ | Surface temperature |
| $V$ | Velocity |
| $\mu$ | Dynamic viscosity |
| $\mu_{bf}$ | Dynamic viscosity of base fluid |
| $\mu_{nf}$ | Dynamic viscosity of nanocoolant |
| $\omega$ | Weight concentration |
| $\varphi$ | Volume fraction |
| $\rho$ | Density |
| $\rho_{bf}$ | Density of base fluid |
| $\rho_{nf}$ | Density of nanocoolant |
| $\rho_p$ | Density of particle |
| $\phi$ | Volume concentration |
| $\phi_1$ | Initial volume concentration |
| $\phi_2$ | Final volume concentration |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AHSS | Advanced High Strength Steel |
| $Al_2O_3$ | Aluminium Oxide |
| ASTM | American Society for Testing and Materials International |
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| BR | Base Ratio |
| CuO | Copper Oxide |
| EG | Ethylene Glycol |
| FESEM | Field Emission Scanning Electron Microscopy |
| FEA | Finite Element Analysis |
| FLD | Forming Limit Diagram |
| FCNT | Functionalised Carbon Nanotube |
| DIN EN ISO | German Institute European Standard |
| HTC | Heat Transfer Coefficient |
| HSS | High Strength Steel |
| HTCS | High Thermal Conductivity Tool Steel |
| HPF | Hot Press Forming |
| SKD | Hot Work Tool Steel |
| IUPAC | International Union of Pure and Applied Chemistry |
| LOM | Light Optical Microscopy |
| MWCNT | Multi-walled Carbon Nanotube |
| SEM | Scanning Electron Microscopy |
| SiC | Silicon Carbide |
| $SiO_2$ | Silicon Oxide |
| TEM | Transmission Electron Microscopy |
| UHSS | Ultra-High Strength Steel |
| UTM | Universal Tensile Machine |
| W | Water |

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